ISOLATORS IN FINLINE TECHNIQUE

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ABSTRACT

A novel configuration for finline isolators is presented. The magnetic bias field is perpendicular to the broad wall of the ferrite slab, combining resonance-type with field-displacement operation. 40 % bandwidth in X-band with an insertion loss of 1 dB was obtained, an extension to higher frequencies is straightforward.

1. INTRODUCTION

Up to now, finline isolators have been designed by placing a ferrite slab parallel to the substrate, and magnetizing it in the same plane normal to the direction of propagation /1/-/3/. This straightforward generalization of waveguide isolators is probably not the best approach for finlines. Two disadvantages are inherent to this design:

- Because of the heigth-dependence of the fundamental finline mode there is no plane of constant polarisation parallel to the substrate.
- The maximum concentration of fields is close to the slot and thereby far away from all waveguide walls. This causes difficulties in applying strong magnetic bias fields.

2. NEW CONFIGURATION

The new configuration is derived from the geometry of our tangentially coupled finline circulator /4/. The basic idea is to introduce a 90° rotation of polarisation for the electromagnetic fundamental mode fields on one side of the substrate. This is achieved by the close vicinity between one waveguide sidewall and the substrate, accompanied by an eccentric slot position (Fig. 1a). In analogy to the above mentioned circulator, there are regions of circular polarisation parallel to the substrate, leading to nonreciprocal effects in a ferrite slab magnetized perpendicularly to it. The ferrite has direct contact to the waveguide wall and can easily be biased by rare earth magnets. Fig. 2 shows the view from above the substrate.

Fig. 1c emphasizes the relationship to the fundamental mode of a reduced height rectangular waveguide. The finline and a rectangular waveguide of the same cutoff frequency have similar field distributions in the hatched regions of Fig. 1b and 1c. Hence this type of finline should allow an isolator performance comparable to waveguide devices.

3. THEORETICAL BASIS

There are two principles for ferrite isolators: field displacement and resonance absorption. Either type requires different properties of the ferrite material. In the following discussion, we assume a permeability tensor

$$\mu = \mu_0 \cdot \begin{bmatrix} \mu & -j\kappa & 0 \\ j\kappa & \mu & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

with elements $\mu = \mu' - j\mu''$, $\kappa = \kappa' - j\kappa''$ for the ferrite. Above saturation, their behaviour with respect to bias field and frequency is described by Kittel's theory /5/.

The field displacement type isolator uses a broad ferrite slab, operated in the region $\mu_{eff} = \mathrm{Re}[\mu^2-\kappa^2)/\mu'] < 0$. Energy is transported mainly at one edge and thereby dissipated inside a layer of absorber material resulting in one-directional propagation only. However, a substantial portion of the energy is transported inside the ferrite, hence narrow line-width material is needed for low loss. This requirement is met by Yttrium-Iron-Garnet (YIG).

Resonance type isolators are biased near the zero of μ'. Our theoretical investigations revealed that no useful isolator can be operated close to the gyromagnetic resonance, although the magnetic loss μ'' is much greater there. The reason is that in reverse direction a field concentration in the ferrite is essential to make its dissipation effective. In all wave-guiding structures, the region of approximately circular polarisation is only a small portion of the cross-section. This means, that even large losses in this very confined area have only small influence on the overall attenuation. However, the edge-condition at the ferrite-air interface (Fig. 3) shows, that for small μ the normal component of the magnetic field in the ferrite becomes very large. This increases the energy in the ferrite and hence the attenuation. With this bias, the electromagnetic fields in the ferrite are no longer circularly but nearly linearly polarized, due to the large normal component. To suppress the dissipation in forward direction, the ferrite must be placed in a plane of such an elliptical polarisation, that the numerator in the expression for H_n in Fig. 3 becomes also zero in forward direction. Our calculations proved that this effect of field concentration is the governing effect for the isolation of resonance type isolators. Of course, sufficiently

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large imaginary parts of μ and κ are required even at this bias, hence we need a ferrite with large linewidth. NiZn-ferrites are appropriate for this purpose. Also hexagonal ferrites, which are well suited for higher frequencies due to their anisotropic field, have quite large linewidths.

4. NUMERICAL RESULTS

For the design of our isolators we developed a computer program which calculates the propagation constants of parallel plate structures having arbitrary full height layers in transversal direction (Fig. 4). The outer boundaries can be open or short-circuits, the layers may have arbitrary complex permittivities and may be gyrotropic.

To apply this program to fin-line structures, an equivalent waveguide was derived which models the frequency behaviour of the finline in the frequency region of interest. This is done by making the distance ℓ between the section a-a and the left wall (Fig. 1c) frequency-dependent: Further investigations using /6/ pointed out that this is a sufficient representation of the real configuration left ot the line a-a, since the stringing fields of the slot have decayed at the ferrite-air interface.

In the following, we will discuss some examples. Fig. 5 shows the amplitude of the field components of a field displacement type isolator. The displacement effect becomes smaller with increasing frequency, causing an increased insertion loss. The device is inherently broad-banded, but the isolation to insertion loss ratio is only 10...15. Improvement by using a wider ferrite slab is limited by the propagation of higher-order modes, which arise due to its high dielectric instant.

The resonance type isolator, consisting of a thin ferrite layer on a high-permittivity dielectric slab, is shown in Fig. 6. The dielectric slab enhances isolation very effectively. The isolation is maximum at the frequency at which $\mu' = 0$. Insertion loss is about 0.01 dB/mm and the isolation to insertion loss ratio is better than 100. The bandwidth, however, is narrow. This can be overcome by tapering the bias field in longitudinal direction, e.g. by inclined pole piecesi causing a spacially dependent resonance frequency spatially dependent. Forward loss is hardly affected by this modification, but the overall length must be increased to maintain a certain isolation.

Beyond that we found the possibility to combine the advantages of both principles. The corresponding cross-section is shown in Fig. 7. A wide, weakly magnetized ferrite slab is combined with a small ferrite layer biased for resonance absorption ($\mu' \approx 0$). This creates a field displacement type isolator with an absorber that depends on the direction of propagation. In contrary to the field displacement type isolator, the displacement effect may be less pronounced and the condition $\mu_{eff} < 0$ can be omitted. Hence we can use a moderate linewidth ferrite. It is even possible to use a single ferrite for displacement and resonance absorption. So we need only one ferrite slab, which is biased inhomogeneously with respect to the transversal coordinate. The frequency dependence is similar to that of the resonance isolator, but the isolation is about twice as large.

5. EXPERIMENTAL RESULTS

Fig. 7...9 show measured results. Fig. 8 shows a resonance type isolator with homogeneous bias field. The 0.254 mm ferrite slab (TT 2-390, Trans-Tech) is stuck with a 3 mm slab of dielectric ($\varepsilon_r = 10$). The length of the isolator is 50 mm. There is a 30 dB isolation band, whose center frequency can be arbitrarily shifted along the frequency axis by the bias field. Insertion loss is about 1 dB with increasing tendency to higher frequencies. Tapering of the bias-field enlarges bandwidth (Fig. 9). It is worth noting that even with low-loss YIG-material (G 113, Trans-Tech) resonance isolators are achievable with about half the isolation per length as with NiZn-ferrites.

By enlarging the width of the ferrite slab, the resonance type isolator passes over to the resonance-displacement type isolator. The bias field must be strongly inhomogeneous in transversal direction in order to confine losses to only one side of the ferrite. This can be achieved by a suitable shape of the pole piece of the magnet.

For the isolator whose performance is shown in Fig. 10, only a single ferrite (YIG) (3.2×50 mm^2) is used. Absorber- or displacement-type of operation is only determined by the local strength of the bias field. The bias field is also tapered in propagation direction. Isolation is -25 dB over the waveguide band, insertion loss 0.5 ... 1.5 dB. With two different kinds of ferrite (YIG for displacement, NiZn for absorption), similar performance can be achieved with about half the length. In this configuration, rather low bias is required, so we can use the direct field of small rare earth magnets without magnetic return path. Shaping of the bias field is achievable by a small iron plate below the substrate. The insertion loss is somewhat higher, due to the higher losses in NiZn-ferrite. Note that the ferrite section was only about one wavelength long. Matching to the finline ports was done by quarter-wave sections with low permittivity ($\varepsilon_r = 3$) inserts.

A pure displacement type isolator could only be realized with moderate performance, because the bias for sufficient field concentration at one edge of the ferrite was too high to avoid magnetic loss in this area. Isolation to insertion loss ratios of greater than 10 can hardly be achieved. For the resonance/displacement type isolator, the loss is much lower because of the lower bias field.

At higher frequencies, the required bias field increases rapidly. In practice, mm-wave isolators should be realized using hexagonal ferrites as absorber material. Thereby the external bias field can be reduced by the internal anisotropy field. For field displacement, YIG can still be used, because only moderate bias fields are necessary. Further investigations with this type of material will be carried out in K- and Ka-band.

6. ACKNOWLEDGEMENT

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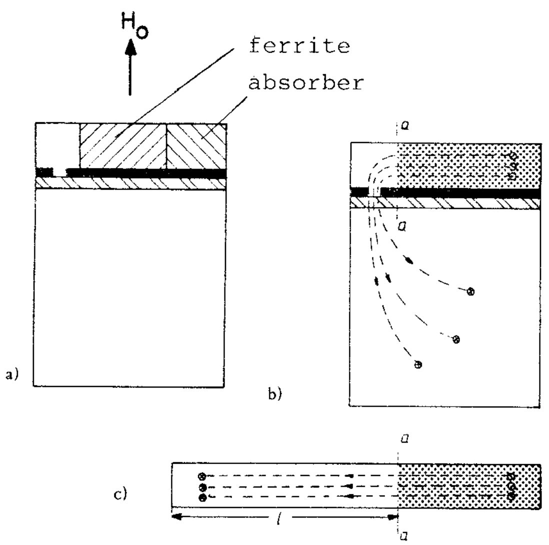


Fig.1: Cross-sections

a) finline isolator

b) empty isolator housing (with magnetic flux lines)

c) equivalent rectangular waveguide (with magnetic flux lines)

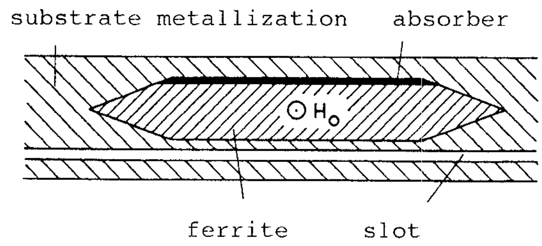


Fig.2: finline isolator configuration

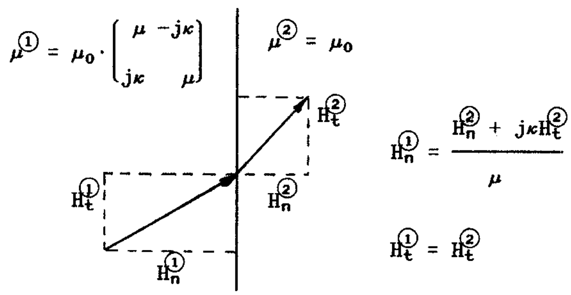


Fig.3: Boundary conditions for the magnetic field at ferrite-air boundary

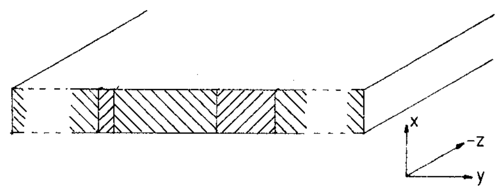
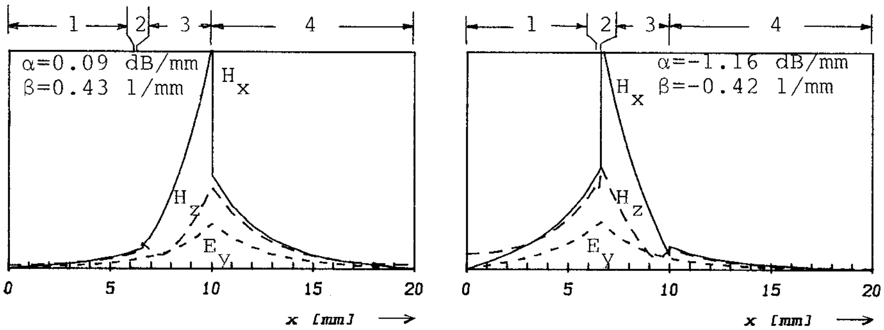


Fig.4: Waveguide model



a)

b)

Fig.5: Field components of field-displacement isolator

a) forward

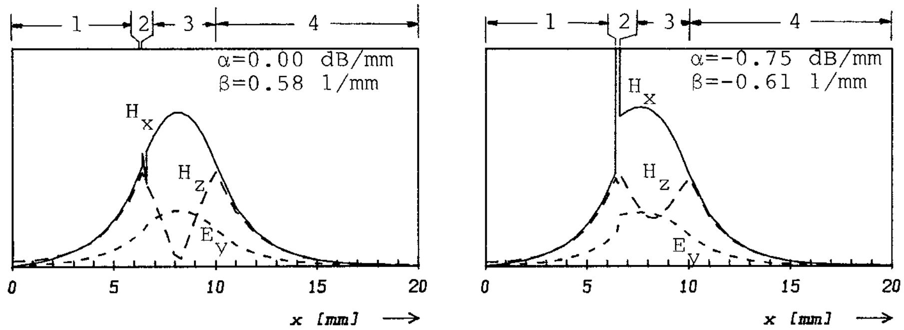
b) reverse

1: air

2: $\varepsilon_r = 2.2 - j50$

3: YIG, $H_{ext}/M_s = 2.0$

4: air



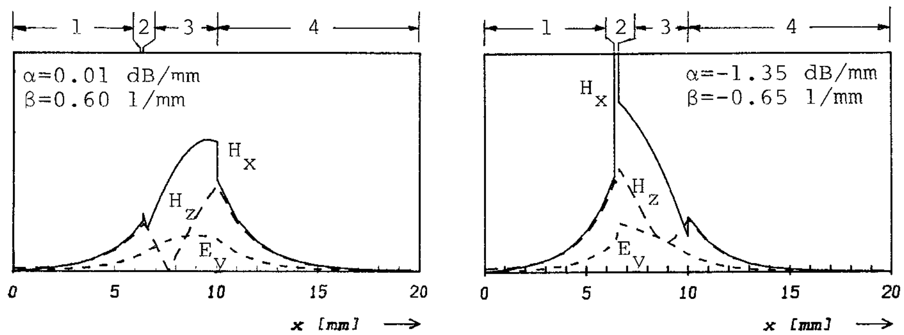
a)

b)

Fig.6: Field components of resonance type isolator

a) forward
b) reverse

1: air
2: NiZn, $H_{ext}/M_s = 2.25$
3: $\varepsilon_r = 12.7$
4: air



a)

b)

Fig.7: Field components of resonance/displacement type isolator

a) forward
b) reverse

1: air
2: NiZn, $H_{ext}/M_s = 2.25$
3: YIG, $H_{ext}/M_s = 0.8$
4: air

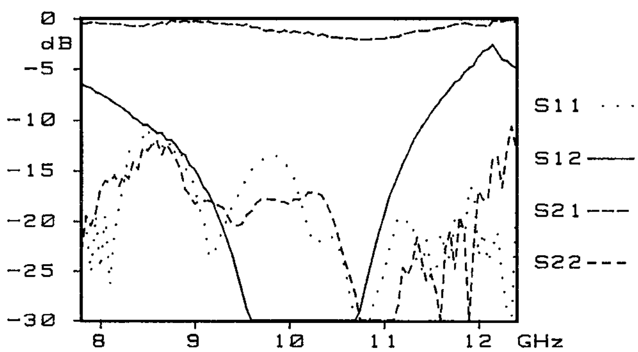


Fig.8: Resonance type isol., constant bias field

Common data to fig 5...7:

dimensions:

region 1: x = 0 ... 6.4 mm
region 2: x = 6.4 ... 6.6 mm
region 3: x = 6.6 ... 10 mm
region 4: x = 10 ... 20 mm

data of ferrite materials:

NiZn: M_s = 215 mT; ΔH = 54 mT; ε_r = 12.7
YIG: M_s = 176 mT; ΔH = 4.5 mT; ε_r = 15

frequency 10 GHz
H_{ext} = external magnetic bias field
$\gamma = \alpha + j\beta$ = propagation constant

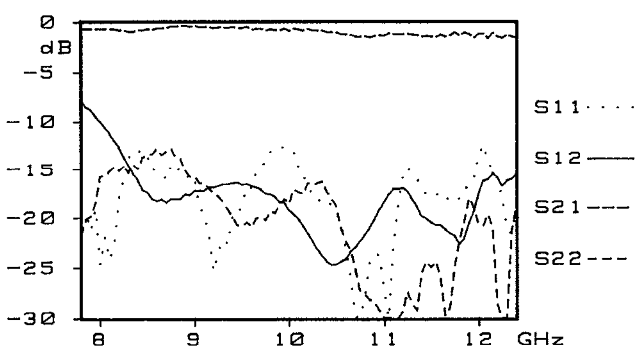


Fig.9: Resonance type isol., tapered bias f.

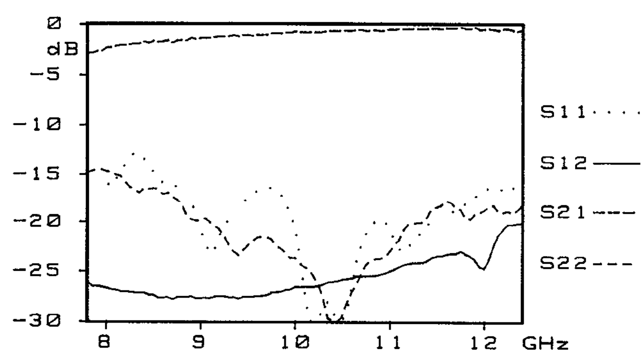


Fig.10: Resonance/displacement type isolator, tapered bias field